TECHNICAL MEMORANDUM

PERMITTABLE WATER USE ESTIMATES
OF THE
FLORIDAN AQUIFER SYSTEM
IN THE
UPPER EAST COAST PLANNING AREA

A Technical Support Study for the
Resource Control Department

Richard F. Bower

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Hydrogeology Division
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EXECUTIVE SUMMARY

The entire Upper East Coast Planning Area is a discharge area for the Floridan Aquifer System. Throughout most of the area, the potentiometric surface of the Floridan Aquifer System is not only above the water table, but also above land surface by as much as 15 to 35 feet.

In order to protect legal uses of the Floridan Aquifer System from loss of free flow from wells not equipped with pumps, the South Florida Water Management District (SFWMD) has adopted a rule generally prohibiting installation of pumps on Floridan Aquifer System wells in Martin and St. Lucie Counties for the purpose of increasing natural flow rates.

In 1981, SFWMD's Resource Control Department staff evaluated irrigation water use and surface water management systems for a proposed 11,833-acre citrus grove located in northwestern St. Lucie County. It was determined that the maximum withdrawal rate which could be made without the installation of pumps on proposed wells is 14 MGD, which is equivalent to 1.5 inches per acre per month. The criterion of a maximum month allocation of 1.5 inches per acre was extended to include the entire western C-25 basin in SFWMD Permit Information Manual, Volume III, Management of Water Use, adopted June, 1985.

Application of the 1.5 inch per acre maximum month allocation criterion to all of Martin & St.Lucie Counties has been suggested. However, some evaluation of the reliability and reasonability of the use of the criterion on a regional basis is needed. The means for making the evaluation is a numerical flow model developed for the Floridan Aquifer System in the Upper East Coast Planning Area. The Floridan Aquifer System is viewed conceptually as three layers; the Upper Floridan Aquifer, the intra-aquifer confining bed, and the Lower Floridan Aquifer. The model simulates conditions in the Upper Floridan Aquifer where most of the flow in the aquifer system occurs, and where most of the wells in the study area are completed.

In the first part of the evaluation process, a withdrawal of 1.5 inches/acre is made from all nodes with positive head relative to land surface; simulated drawdown is well below land surface in all nodes, demonstrating that a maximum month criterion of 1.5 inches/acre cannot be applied regionally without ultimately causing free flow from Floridan wells to cease.

In the next part, the model was run iteratively to determine maximum withdrawal which could be made from each node while still maintaining some positive head. By attempting to maximize withdrawals throughout the aquifer, rates as high as the proposed 1.5 inches/acre are obtained in few nodes.

It is concluded that the 1.5 inches/acre limitation is valid, but only site-specifically; regional application generates drawdowns which cause free flow to cease. It is recommended that interim water use management be accomplished by using the existing two-dimensional model for cumulative impact evaluations of new or increased allocations from the Floridan Aquifer System and that the model be redeveloped using a fully three dimensional flow code for use in the ultimate management strategy for the Floridan Aquifer.

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ACKNOWLEDGEMENTS

The author thanks the following individuals for invaluable assistance in the development of this report: Sharon Trost, who developed the prototype of the finite-difference model used in this project, and who provided knowledge and insight based upon her previous work with the Floridan Aquifer system in the Upper East Coast Planning Area; Diane Bello, who prepared most of the illustrations in this report; and Hedy Marshall, who prepared the text portion of the report in various drafts as well as the final version.

ABSTRACT

The regional applicability of certain District rules governing withdrawals from portions of the Floridan Aquifer System are evaluated using a finite-difference flow model. The United States Geologic Survey two-dimensional flow code is used in a quasi-three-dimensional configuration; upward leakance from the lower to the upper Floridan Aquifer System is simulated by leakage and diffuse upward leakance from the upper Floridan Aquifer System is simulated as negative recharge. Imposed stress from agricultural withdrawals, the least reliably known parameter, is used to obtain the final calibration. The regional applicability of a rule limiting Floridan Aquifer withdrawals to 1.5 acre-inches per month is evaluated by applying that rate to all model nodes corresponding to areas where free flow occurs; the drawdown generated in this scenario causes all water levels in the Floridan Aquifer System to fall below land surface, meaning that freeflow from wells would cease. The rule forbidding installation of pumps on flowing wells, thereby limiting drawdown in the Floridan Aquifer to land surface, is also evaluated. The model was run iteratively to determine maximum withdrawal from each node while maintaining free flow; generally, nodal withdrawal rates range between 0.1 and 1.0 inch. It is concluded that the 1.5 acre-inch criterion has been validly applied site-specifically, but cannot be applied regionally. The existing two-dimensional model can be used for interim management of the Floridan Aquifer System; however, to more accurately reflect the physical system, particularly when stressed, a fully three-dimensional model with a finer grid is recommended.

INTRODUCTION

In order to protect legal uses of the water from Floridan Aquifer System from loss of free flow from wells not equipped with pumps, the South Florida Water Management District (SFWMD) has adopted the following rule:

> **3.2.2.4.9.2 Pumps on Floridan Wells in Martin and St. Lucie Counties** - No pump shall be placed on a Floridan well in Martin or St. Lucie county except under the following guidelines:
>
> 1) The pump was in place and operational on the well prior to March 2, 1974.
>
> 2) The pump which is proposed for installation, is a centrifugal pump installed for the purpose of increasing pressure in attached piping (i.e. drip or jet irrigation systems) and not for the purpose of increasing flow over and above that flow which naturally emanates from the well...

Prior to the adoption of the rule in 1985, this policy was included as a limiting condition on water use permits issued within the St. Lucie basin.

In 1981, the staff of the Resource Control Department met with the Orange Avenue Growers Citrus Association regarding conceptualization of both irrigation water use and surface water management systems for a 11,833-acre project located in northwestern St. Lucie County. Because water use permits issued to the Association for Floridan Aquifer withdrawals would be subject to the free-flow limiting condition, the Resource Control Department staff decided that the allocations authorized by those permits should reflect the estimated amount of water available from the Floridan Aquifer System while maintaining positive potentiometric pressure above land surface over the project site. An analytical drawdown model emulating the Theis non-equilibrium flow equation was used to estimate the amount of water available. The selected transmissivity value of 500,000 GPD/ft and storativity value of .0005 were estimated from SFWMD Technical Publication 80-1. Representatives of the Orange Avenue Citrus Growers Association informed staff that the longest period of sustained withdrawal from the Floridan would be 90 days. Staff determined that, on the average, potentiometric head in the Floridan Aquifer occurred at 15 feet above the land surface of the project site. Utilizing these parameters, the Theis model was set up to simulate 60 withdrawal points located on half-mile centers throughout the project site, then run at increasing withdrawal rates until a projected drawdown which was slightly less than 15 feet was obtained (Appendix A). This condition was produced by a withdrawal of 14 MGD, which is equivalent to 1.5 acre-inches per month applied to 10,640 proposed irrigated acres.

In February, 1984, Water Use Permit 56-00473-W was issued to Orange Avenue Citrus Growers Association authorizing withdrawals from the Floridan Aquifer not to exceed 381 MG/month (1.5 acre-inches X 9358 acres). The criterion of a maximum month allocation of 1.5 acre-inches was extended to include the entire western C-25 basin in SFWMD Permit Information Manual, Volume III, Management of Water Use, adopted June, 1985, as follows:

> **3.2.2.4.9.1 Allocation of Floridan Aquifer Water in the Eastern Okeechobee-Northwestern St. Lucie Basin** - When the project site is located within the Eastern Okeechobee-Northwestern St. Lucie basin, withdrawals from the Floridan Aquifer are limited to 1.5 inch for the maximum month, with the balance of the water needs being withdrawn from other sources.

Application of the 1.5 acre-inch maximum month allocation criterion to all of Martin & St.Lucie Counties has been suggested. However, some evaluation of the reliability and reasonability of the use of the criterion on a regional basis is needed.

The means for making the evaluation is a numerical flow model developed as part of an unpublished report of the hydrogeology of the Floridan Aquifer System in the Upper East Coast Planning Area. Although the Floridan Aquifer System is multi-layered within Martin & St.Lucie Counties, unavailability of the USGS three-dimensional modular flow code (MODFLOW) at the time of model development required use of the USGS two-dimensional flow code instead. A quasi-three-dimensional approach is used, whereby leakance from the lower to the

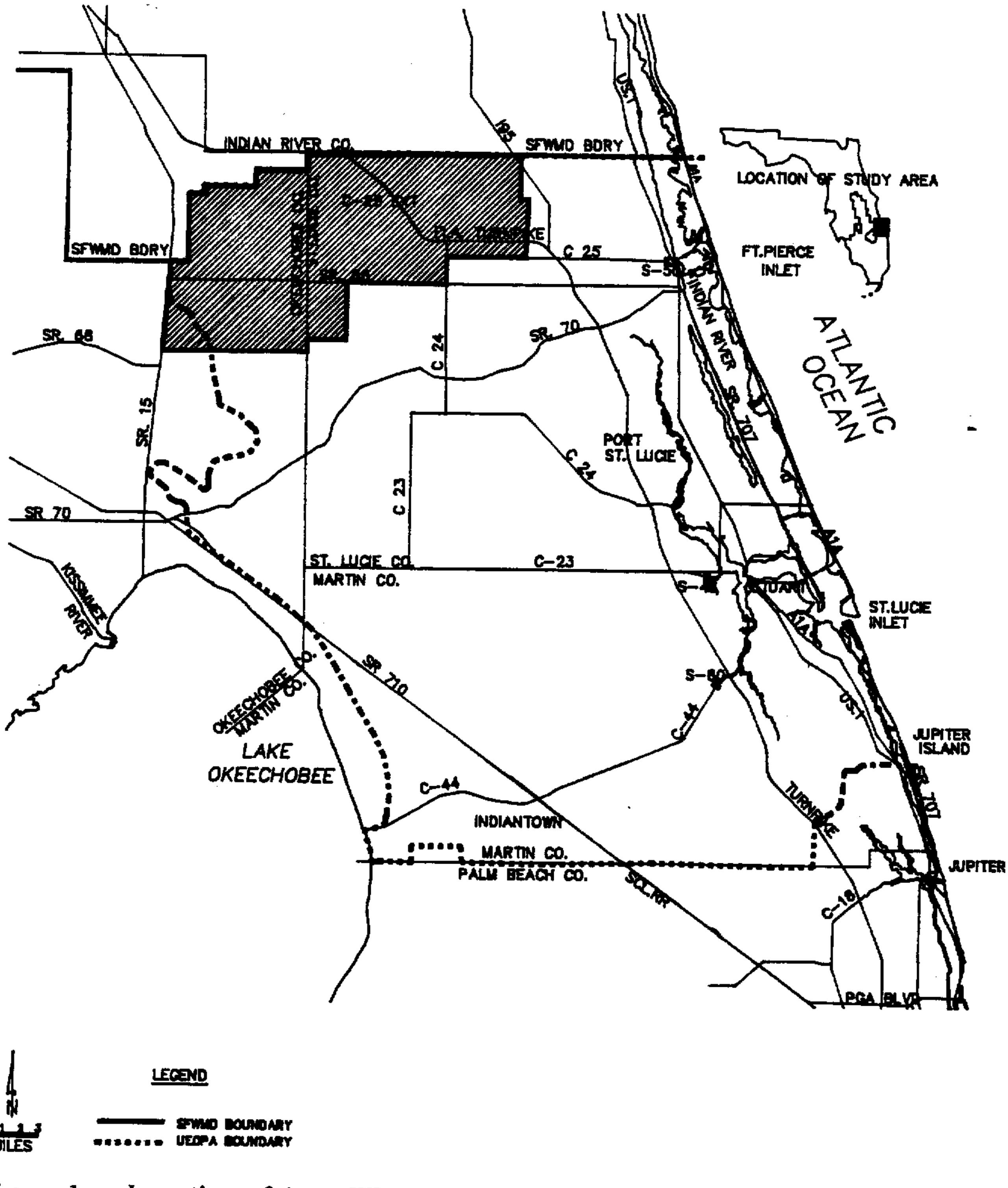

Figure 1. Location of Area Where Maximum Month Withdrawals from the Floridan Aquifer are Limited to 1.5 Inches

upper Floridan Aquifer System is simulated with the leakage option of the code, and diffuse upward leakance out of the Upper Floridan Aquifer is simulated as negative recharge.

COMPUTER SIMULATION OF GROUND WATER FLOW IN THE UPPER FLORIDAN AQUIFER SYSTEM

Introduction

The pre-development steady-state flow system is simulated in order to quantify the volume of water flowing through the aquifer prior to development and to verify time-invariant parameters. Then, current flow conditions in the Upper Floridan Aquifer are simulated by applying the stresses due to agricultural withdrawals, completing the calibration process.

Hydrogeologic Setting

The entire UECPA is a discharge area for the Floridan Aquifer System. Throughout most of the study area, the potentiometric surface of the Floridan Aquifer System is not only above the water table, but also above land surface by as much as 15-35 feet (Figure 2); it is at or slightly below land surface only in a few localized topographic highs in southwestern St. Lucie County, eastern Okeechobee County and on the tops of some sandhills in eastern Martin County. However, the great thickness and overall low permeability of the Hawthorn Confining beds appears to preclude any appreciable vertical movement of water between the Floridan Aquifer System and the Surficial Aquifer System. Therefore, it is ignored in the simulation.

Within the study area, the Floridan Aquifer System is viewed conceptually as three layers; the Upper Floridan Aquifer, the intra-aquifer confining bed, and the Lower Floridan Aquifer (Figure 3). The model simulates conditions in the Upper

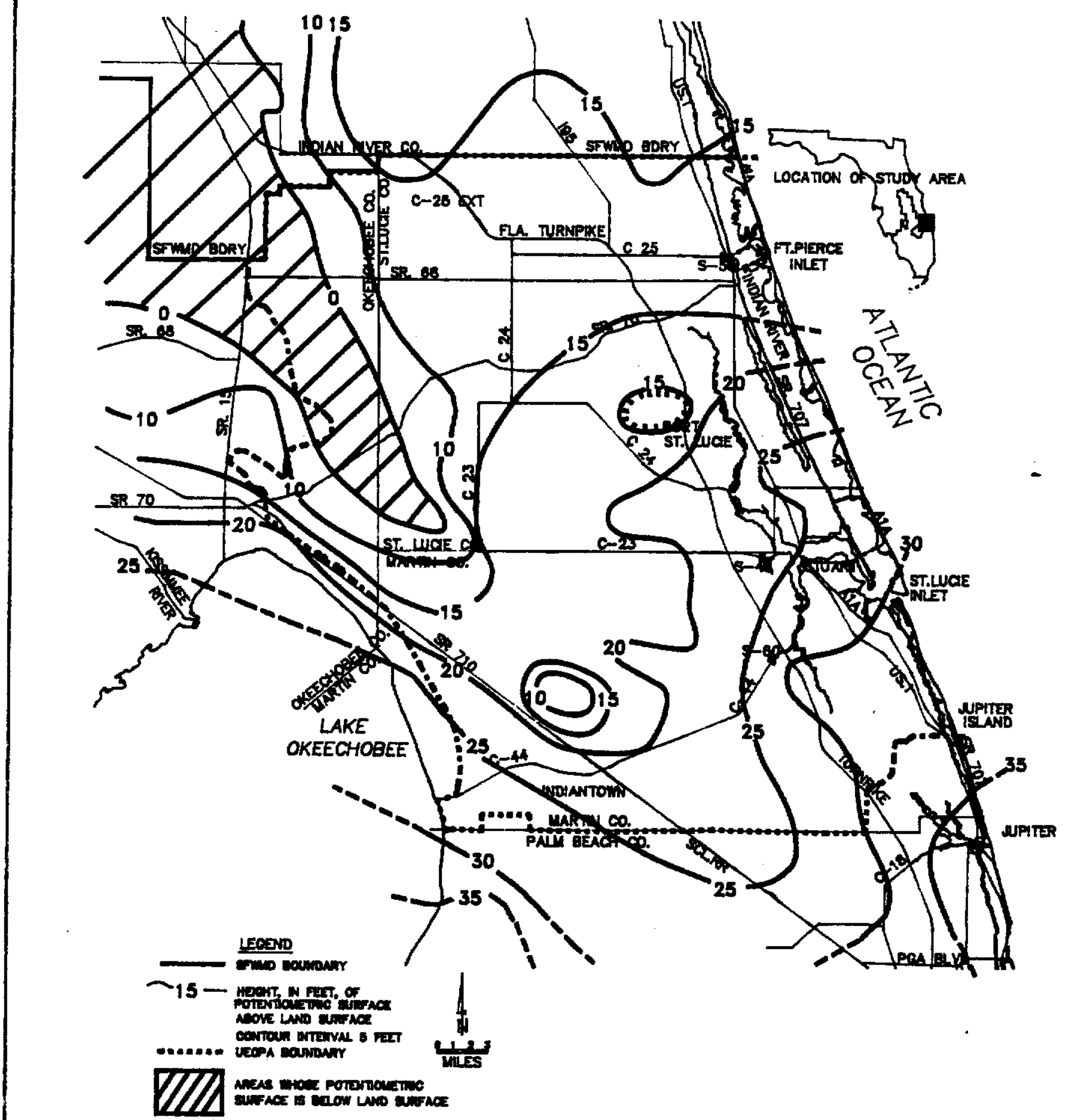

Figure 2. Approximate Height of the Potentiometric Surface of the Upper Floridan Aquifer Above Land Surface, September 1983

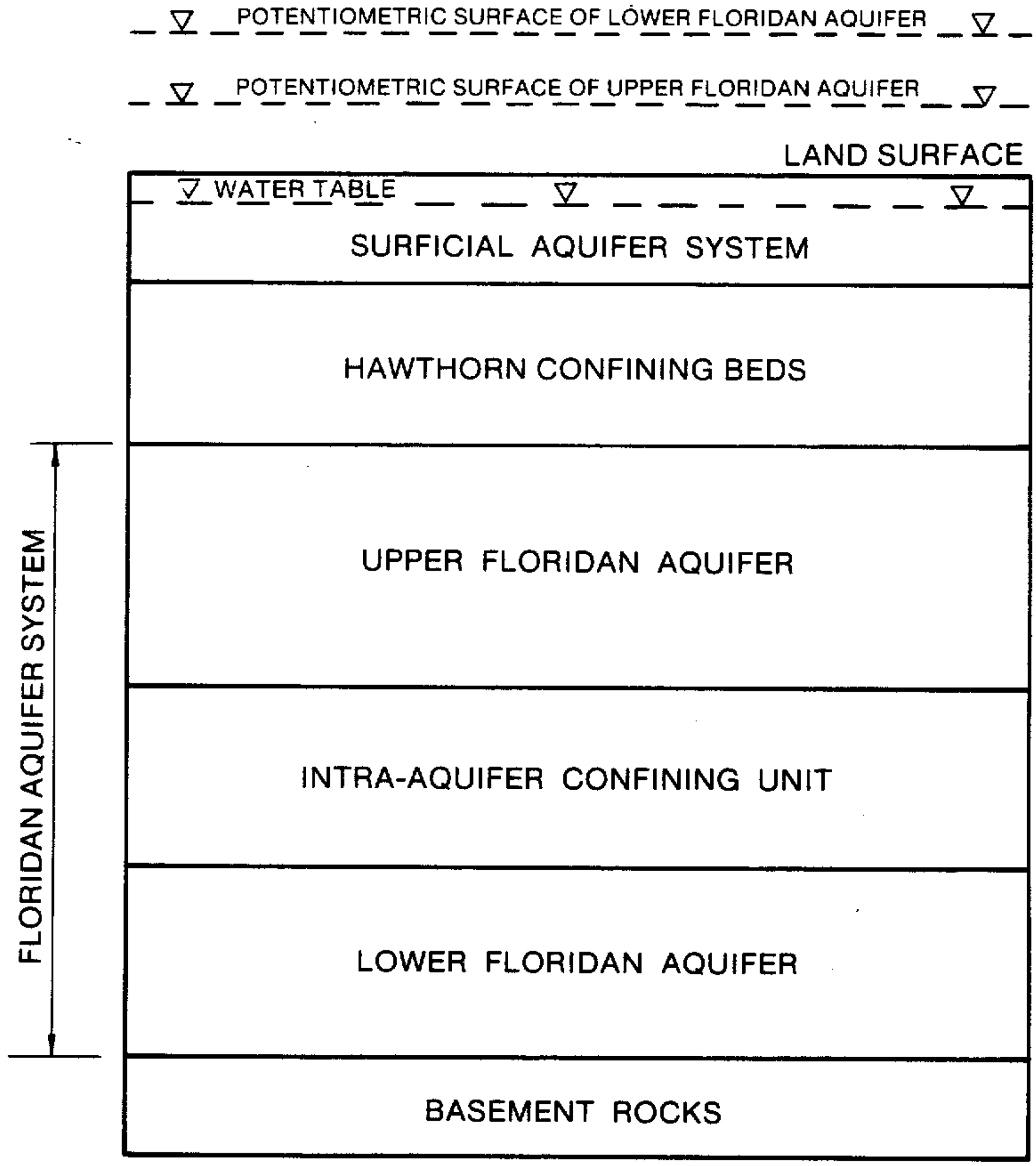

Figure 3. **Conceptual Model of Principal Hydrogeologic Units and Respective Water Levels in the UECPA**

Floridan Aquifer where, according to Tibbals (1981), most of the flow in the aquifer system occurs, and where most of the wells in the study area are completed. In the model the Floridan Aquifer System is simulated as a leaky artesian system, with the intra-aquifer confining unit regulating upward leakance from the Lower Floridan Aquifer. The System is assumed to be underlain by rocks of extremely low permeability.

The finite-difference model grid comprises 29 rows and 28 columns (Figure 4). Each of the grid blocks is 2 miles on a side, or 4 square miles in area. Of the 812 nodes, 617 are active, representing a surface area of 2468 square miles.

Pre-Development Constant Flux Model

Boundary Conditions: The boundary conditions of the modeled area are determined by the configuration of the potentiometric surface of the Upper Floridan Aquifer. The southern boundary of the model is perpendicular to the pre-development potentiometric contours; therefore, it is modeled as a no-flow boundary. A constant flux boundary condition is selected for the remaining model borders. An estimate of the flow across these boundaries is determined through a flow net analysis which demonstrates that approximately 2.59 ft^3/sec (1.7 MGD) of water is flowing through the Upper Floridan prior to development, as depicted in Figure 5.

Hydraulic Head: The starting head for each node of the Upper Floridan Aquifer is derived from the predevelopment potentiometric surface map (Figure 6). According to Tibbals (1981), existing data suggest that in discharge areas of the Floridan Aquifer System, heads in the Lower Floridan Aquifer tend to be a few feet higher than those in the Upper Floridan. Therefore, the starting head in the lower Floridan is assigned a value that is 2 feet higher than that determined for the upper Floridan at each node location.

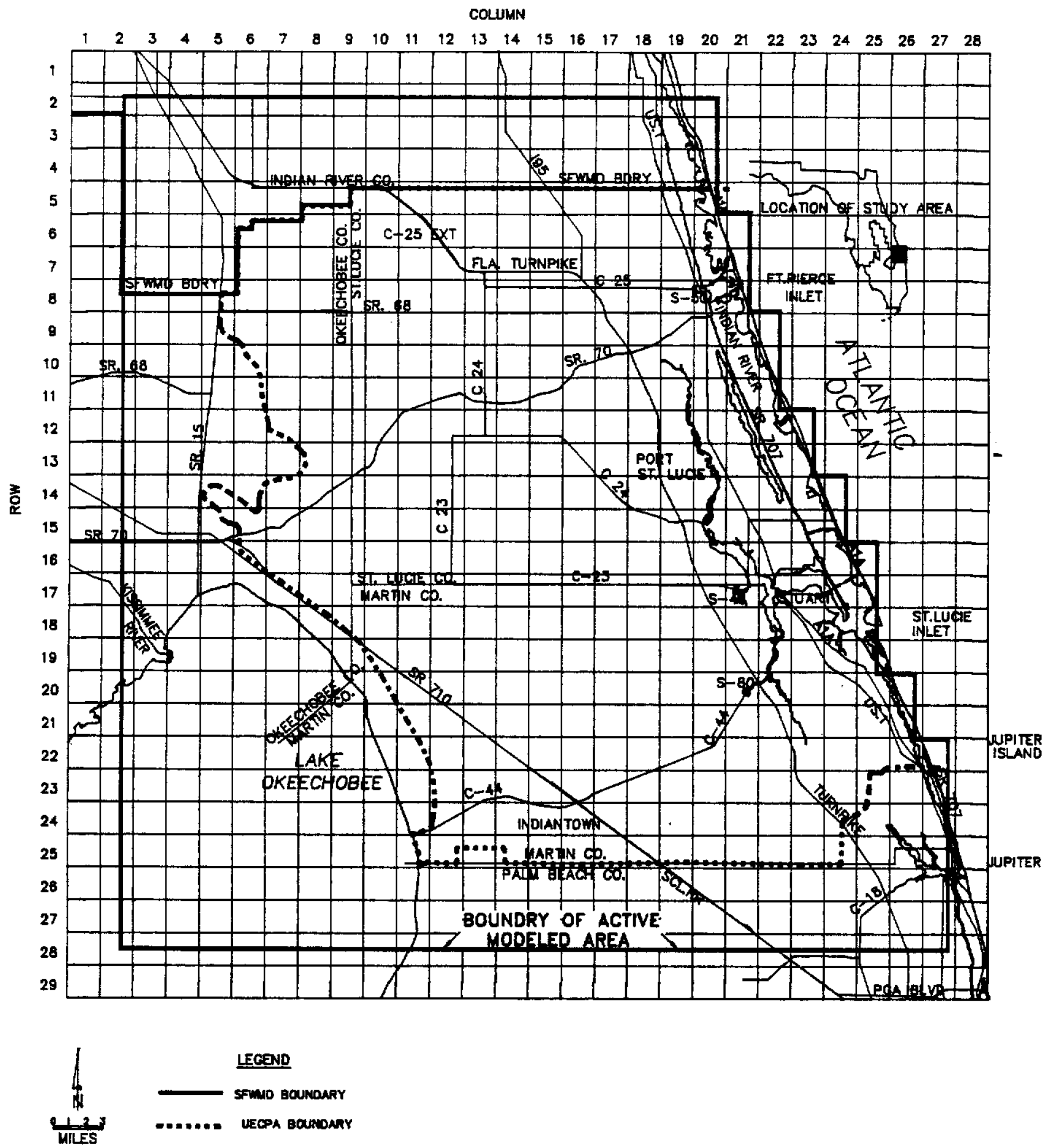

Figure 4. Finite Difference Grid Superimposed on Modeled Area

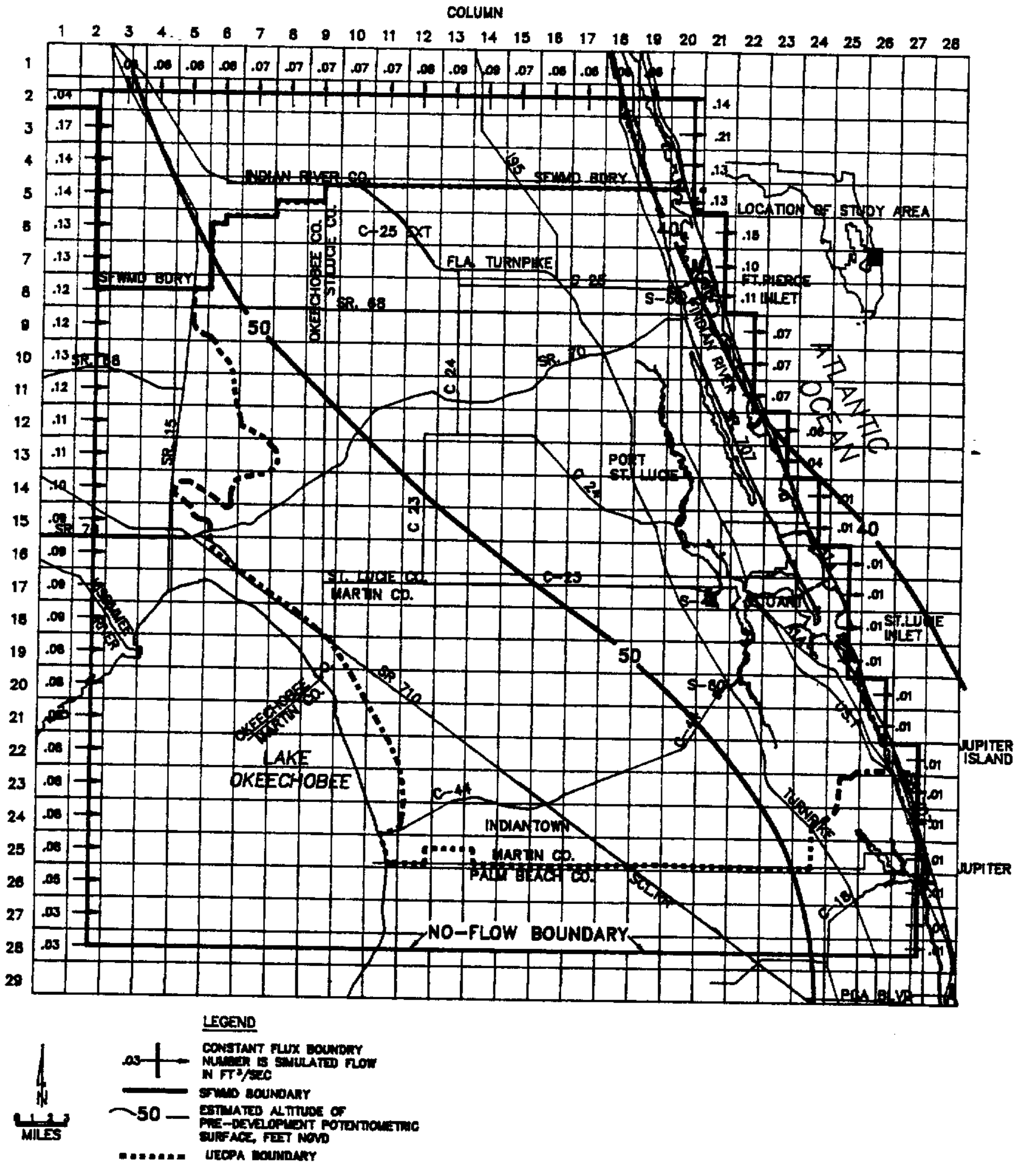

Figure 5. Model Boundary Conditions for the Upper Floridan Aquifer Pre-Development Flow System

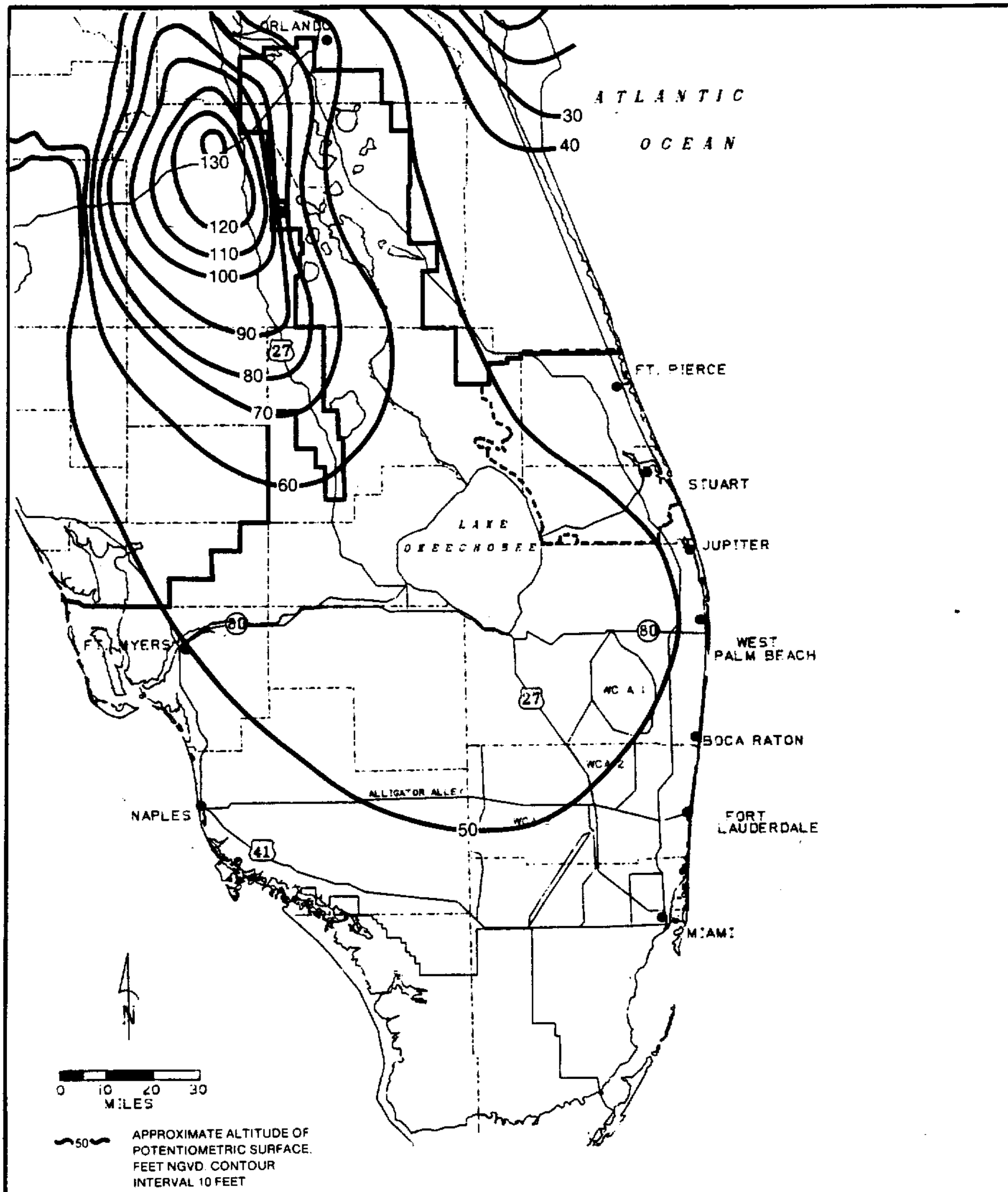

Figure 6. Estimated Pre-Development Potentiometric Surface of the Floridan Aquifer System (Modified from Johnston and Others, 1980)

Storage Coefficient: Since the first model runs are simulating steady-state conditions, a storage coefficient of zero is assigned to the model.

Transmissivity: Aquifer characteristics of the Floridan System in the modeled area were obtained from:

(1) Published values of aquifer parameters.

(2) Analysis of available discharge/drawdown data obtained from tests conducted by SFWMD and Florida Bureau of Geology personnel.

(3) Well driller's reports.

(4) Data developed from aquifer tests performed by SFWMD personnel.

An empirical relationship between specific capacity and transmissivity for wells penetrating the Floridan Aquifer System in the UECPA was developed by performing a regression analysis on 19 values of corrected specific capacity and associated values of transmissivity determined from recovery tests performed by SFWMD personnel. This relationship is described in the equation:

$$\log_{10}(Te) = 4.056 + 0.816(\log_{10}(SCc))$$

Where,

Te = estimated transmissivity value (gpd/ft)

Scc = corrected specific capacity value (gpm/ft)

The correlation coefficient, r, determined in the regression analysis is 0.83; the r^2 value is 0.69.

A total of 54 transmissivity values were obtained by applying this relationship. Because wide variations in the values and their spatial distribution in the study area exist, the technique of kriging was utilized to generate a heterogeneous transmissivity matrix for the study area. When multiple transmissivity data points were clustered in a model cell, the geometric mean of the points was used. A detailed explanation of the assumptions used in kriging can be found in Shrivan and Karlinger, 1983.

A heterogeneous transmissivity matrix consisting of 525 values was generated through kriging analysis (Figure 7). The highest transmissivity value obtained was 367,000 gpd/ft, and the mean transmissivity value was 133,400 gpd/ft.

Leakance: The USGS two-dimensional model provides only one set of arrays to directly simulate leakance. In order to utilize the model as quasi-three-dimensional, diffuse upward leakance out of the Floridan Aquifer System is simulated by negative recharge. The leakance calibration process required two steps.

Because all components controlling leakance were reasonably well known except for hydraulic conductivity of the intra-aquifer confining bed, the first step involved combining these parameters within the model leakance-control arrays and calibrating to pre-development heads using hydraulic conductivity of the confining bed (RATE) as the calibration parameter. It was then assumed that, because of the great thickness and low permeability of the Hawthorn confining beds, the diffuse upward component of leakance through these beds would be relatively uniform over time and could be simulated by negative recharge (-QRE). In the second step of the calibration, the components controlling diffuse upward leakance were withdrawn from the leakance-control arrays and replaced by the appropriate calculated negative recharge rate.

In the calibrated pre-development simulation, the cumulative mass balance demonstrates that the volume of water leaving the Upper Floridan as diffuse upward leakance is nearly equal to that entering as upward leakance from the lower Floridan Aquifer System. These leakance components do not play a significant role in the simulation of steady-state conditions since no stresses have been imposed on the system. However, calibration to obtain the refined values of the hydraulic

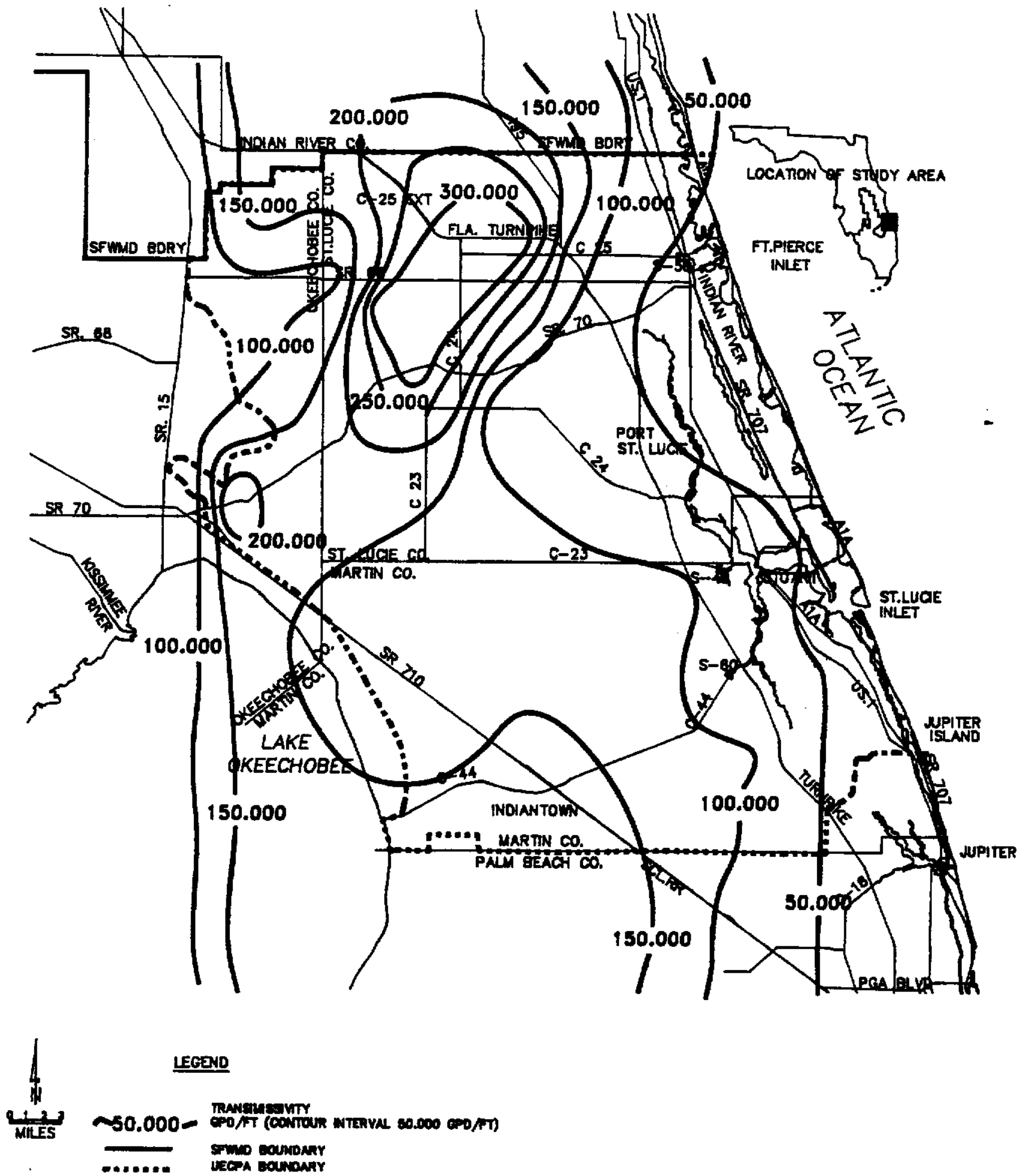

Figure 7. Transmissivity of the Upper Floridan Aquifer

conductivities and thicknesses of the Hawthorn confining bed and the intra-aquifer confining unit. is required for the validation process.

Figure 8 depicts a comparison of observed and model computed heads in the Upper Floridan Aquifer under steady-state conditions. The computed head configuration closely resembles the estimated or observed pre-development head configuration.

Model Validation

The validation process consists of applying current conditions to the calibrated steady-state model to obtain coincidence of model computed heads and a known, measured current head configuration. The September 1983 potentiometric surface map of the upper Floridan (Figure 9) was chosen as the basis for model validation since it comprises the largest number and best areal distribution of reliable head readings compared to other available recent maps.

Boundary Conditions: The model boundary conditions utilized in the validation process are the constant-flux values obtained in the calibration procedure.

Hydraulic Head: The pre-development head distribution in the Upper Floridan is considered to be reasonably accurate, and that of the Lower Floridan is an acceptable estimate. However, in order to use the predevelopment head values in the Upper Floridan as starting heads for the simulation of current conditions, the pumpage or withdrawal history from the aquifer system from the pre-development to the present must be known. Since it is not, the starting heads used in the validation process are obtained from the September 1983 potentiometric surface map. The starting head values in the lower Floridan obtained in the steady-state calibration are initially used in the validation process.

Initial model results showed excessive mounding in the areas of less concentrated usage, and in the areas of heavy withdrawals, the water levels in the

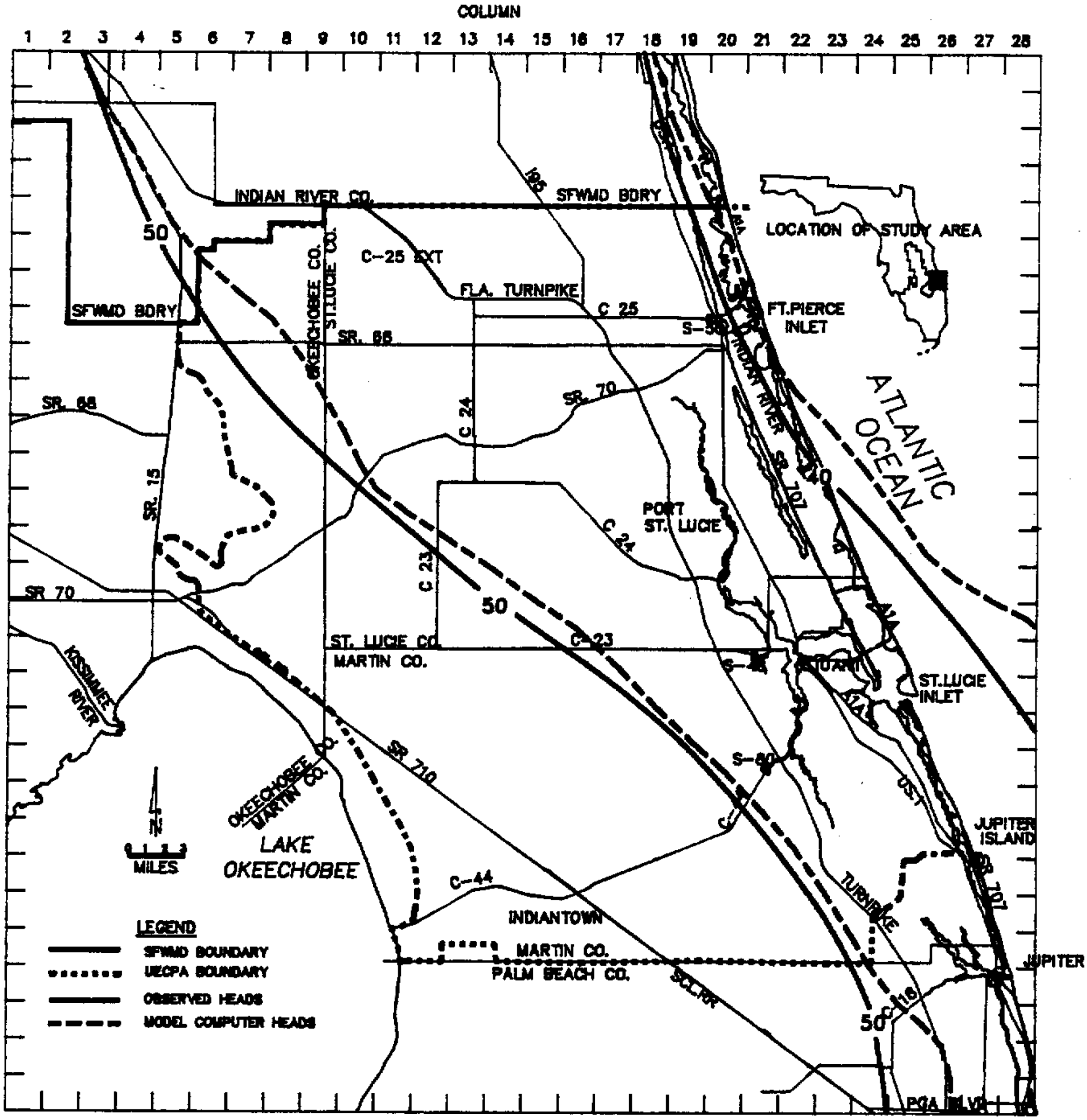

Figure 8. Comparison of Observed (Estimated) and Computed Pre-Development Head Configurations in the Upper Floridan Aquifer

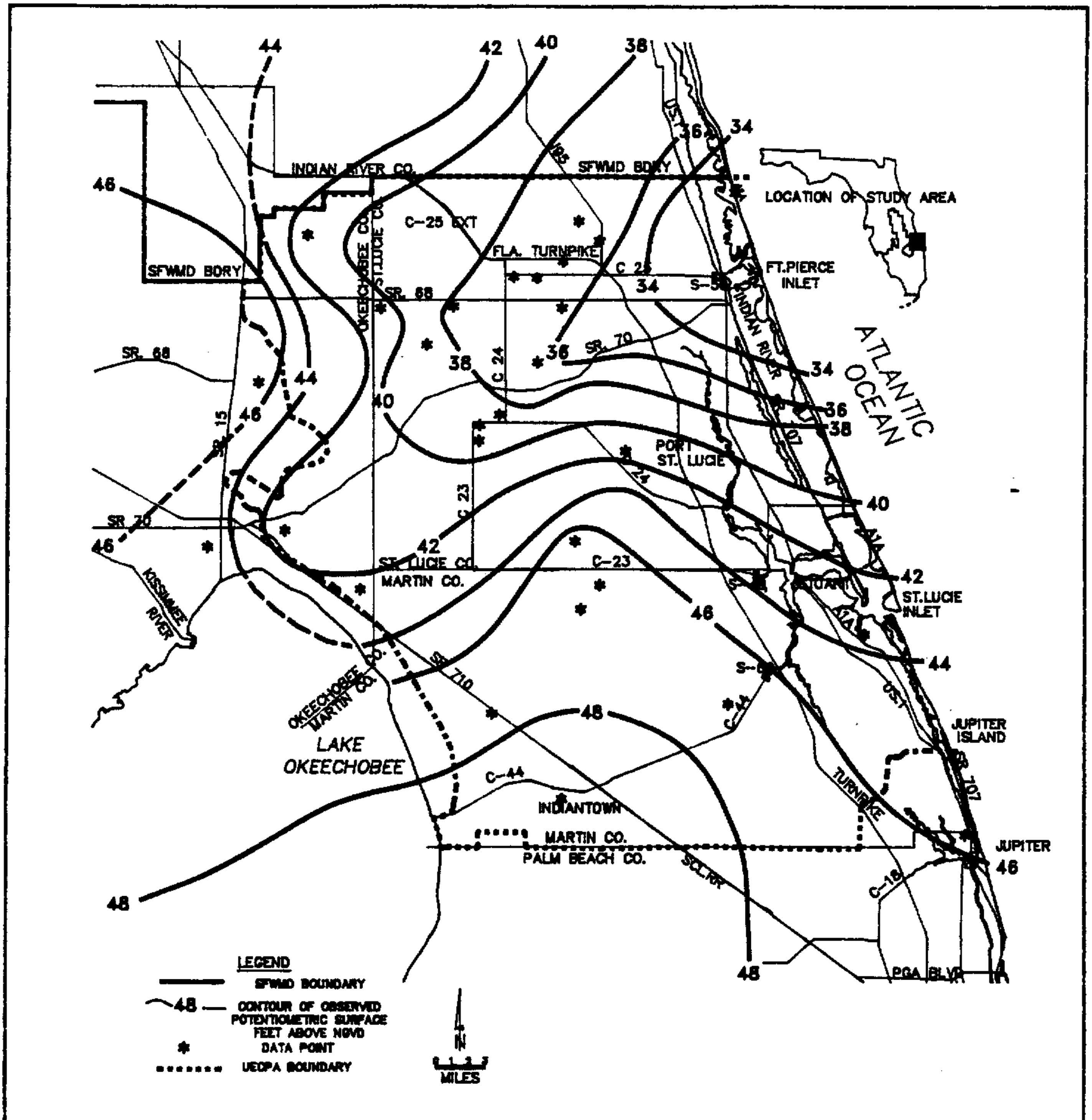

Figure 9. Potentiometric Surface of the Upper Floridan Aquifer, September 1983

upper Floridan were not drawn down sufficiently to reflect current conditions in the area. It was determined that by having set the lower Floridan heads at pre-development levels, an unrealistically high head differential driving the leakance mechanism was created. The degree to which lower Floridan heads parallel those in the upper Floridan under pumping conditions is unknown, but probably varies areally depending upon the thickness and hydraulic conductivity of the intra-aquifer confining bed. In order to more accurately simulate current conditions in the aquifer system, the starting heads in the lower Floridan are assigned values 1-3 feet higher than the September 1983 head values in the upper Floridan.

Storage Coefficient: Based on a review of existing literature and the results of aquifer tests in the area, a uniform storage coefficient of 1×10^{-4} is assigned to all of the active model nodes.

Transmissivity and Leakance: The matrices obtained for transmissivity, confining bed hydraulic conductivity and thickness, and diffuse upward leakance in the calibrated steady-state simulation are utilized in the validation.

Determination of Imposed Stresses

The stresses on the Floridan Aquifer System are via free-flowing well discharges for irrigation of citrus groves and pastures. The amount of water withdrawn from the Floridan Aquifer System is difficult to quantify, because until recently, agricultural water use permittee were not required to submit any formal accounting of their water use. Even when the total amount of water use is known, the practice of using Floridan Aquifer water only in a supplementary manner compounds the difficulty of quantifying the amount of water withdrawn.

In order to arrive at a reasonable estimate for the total discharge from the upper Floridan Aquifer System, a well inventory compiled from the permit files of the Resource Control Department of the SFWMD and data collected by the USGS are examined. Figure 10 shows the locations of known wells completed in the Floridan Aquifer System in St. Lucie County.

Average discharge rates for varying well diameters were obtained from direct measurements taken by SFWMD and USGS personnel, and estimates of discharge from water use permit applications. Discharge rates were also adjusted according to personal communication with cooperators and pumpage reports. The average discharge rates for these free-flowing wells of various diameters are as follows:

Casing Diameter (in)	Average Discharge (gpm)
2-3	75
4	100
5-6	250
8	575
10	850
12	1100

These averages for various well diameters reflect instantaneous discharge rates. Communication with well owners that are cooperators in the SFWMD Floridan Aquifer System monitor well network reveals that many of the wells are discharged for up to five hours per day when in use, which is about 8 or 9 months per year. In addition, all of the wells on a given property may not be in use simultaneously. The total pumpage rates were adjusted accordingly.

The average discharge values applied to the well density distribution provides the discharge rate for each nodal block. In this manner, discharge values from

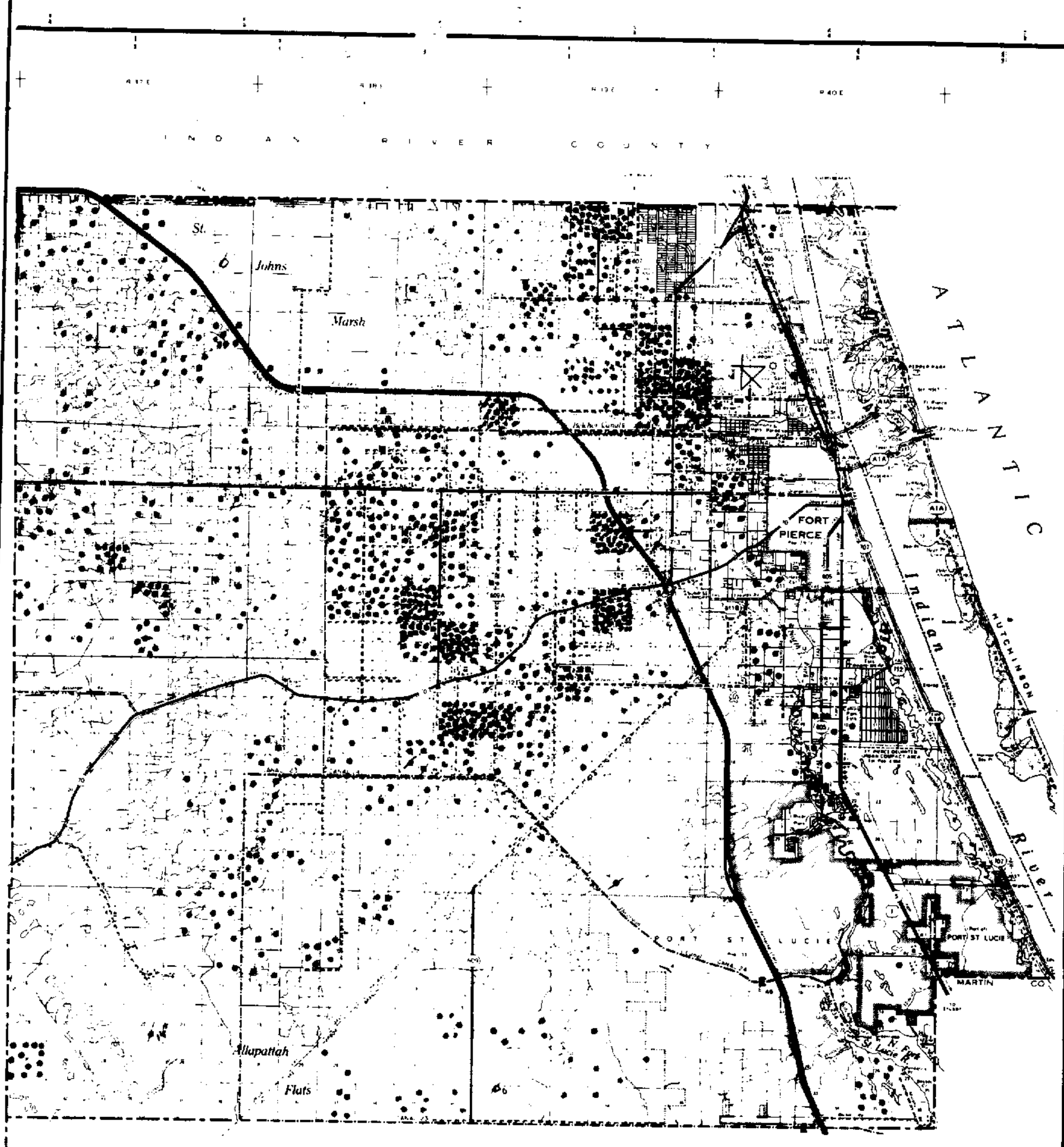

Figure 10. **Locations of Known Floridan Aquifer System Wells in St. Lucie County (Compiled from SFWMD Permit Files)**

multiple wells within a node are accumulated to arrive at a withdrawal rate which is averaged over the area of the node. Discharge data from over 1,100 Floridan Aquifer System wells is represented at 154 model nodes.

Validation Approach

The well density distribution is presumed reasonably accurate, but the magnitudes of the withdrawals are not known to a great degree of certainty. Therefore, the withdrawal rate, Q, is used as an estimation parameter to achieve model validation.

The finite difference model was run several times with varying amounts of agricultural withdrawals. The heads in the lower Floridan and the withdrawal rates from the upper Floridan are adjusted until computed heads resemble the September 1983 observed heads.

The head distribution computed by the model in the simulation of conditions in September 1983 is shown in Figure 11. The computed head distribution compares favorably with the observed heads (Figure 8). A contour map of the differences between the computed head and the observed head at each active model node is presented in Figure 12. Negative values for head difference reflect computed heads being less than observed heads; positive values reflect the converse situation. The average absolute difference between computed and observed heads is about 0.8 feet per node in the upper Floridan Aquifer System model.

Most of the northeastern portion of the modeled area where pumpage is concentrated shows a difference of less than one foot between computed and observed heads. This difference is probably well within the range of accuracy of the observed head readings. Computed and observed heads in the upper Floridan also differ by less than one foot in the southeastern and northwestern portions of the modeled area.

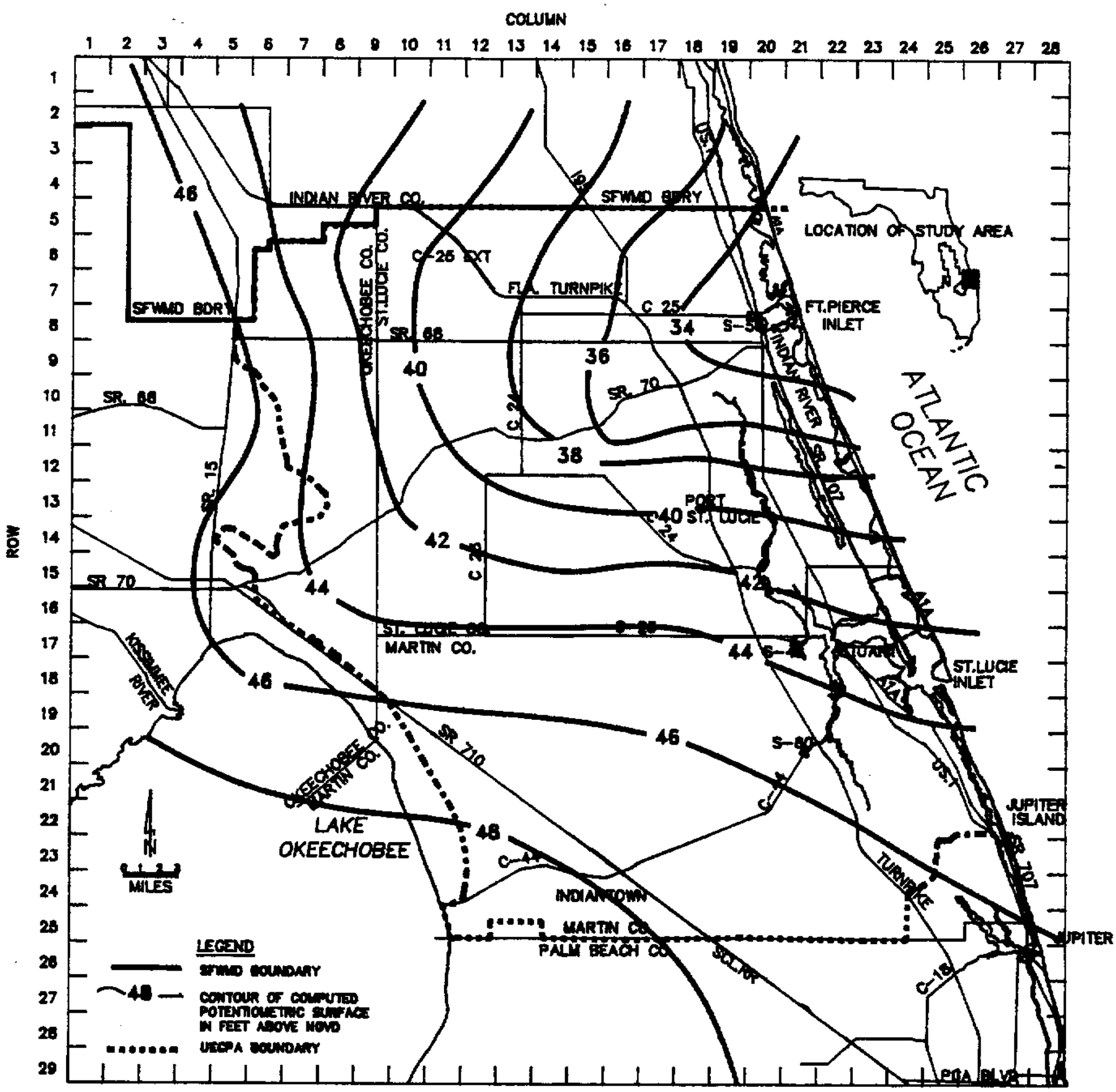

Figure 11. Model Computed Heads in the Upper Floridan Aquifer, September 1983

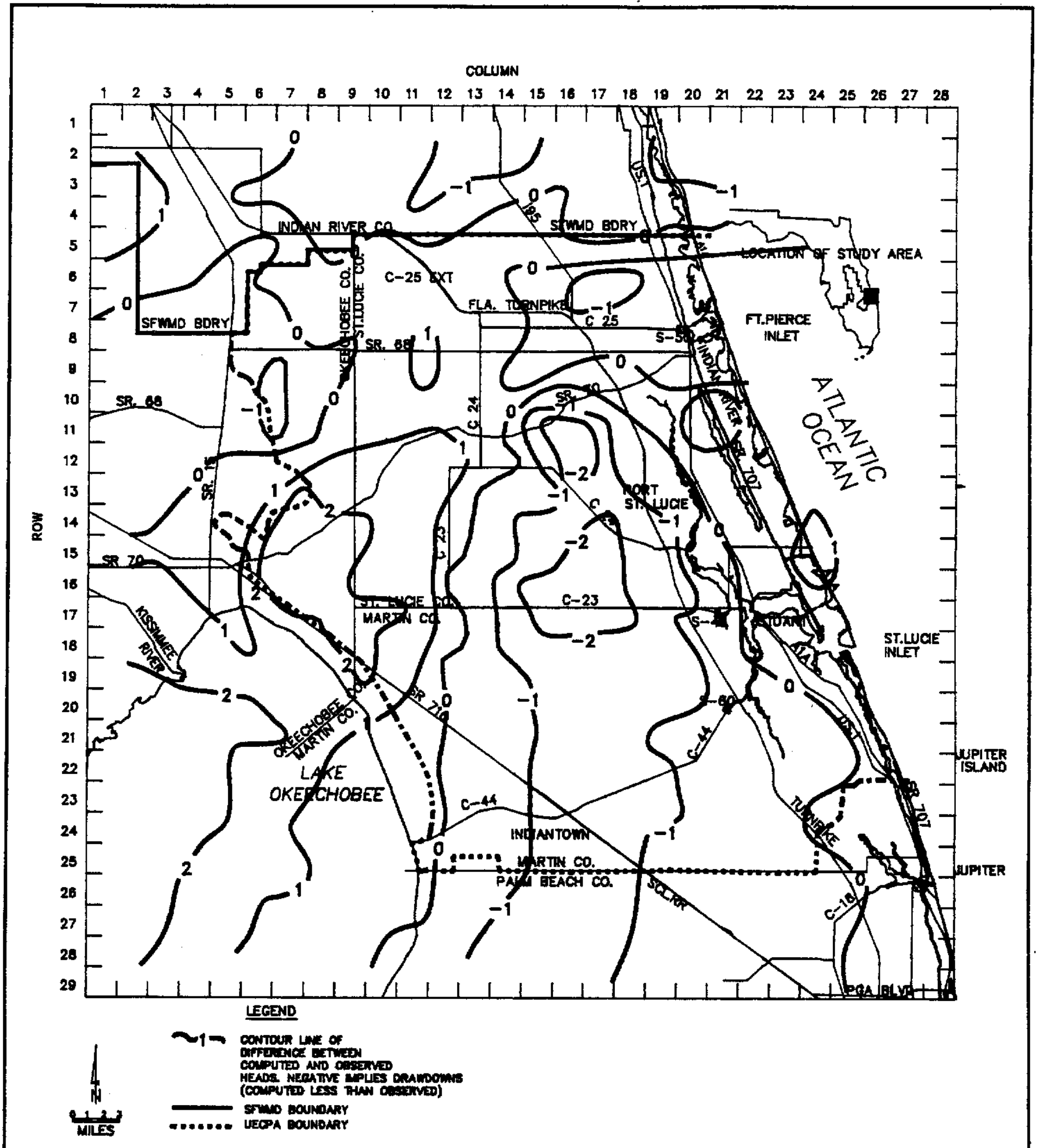

Figure 12. Difference Between Observed and Computed Heads in the Upper Floridan Aquifer, September 1983 Conditions

The greatest head differences occur in two localized areas east and west of the center of the modeled area. The maximum difference between computed and observed heads in these two regions is approximately 2.7 feet.

Insufficient withdrawal rates may have been assigned to nodes in the area due north of Lake Okeechobee in which computed head values are more than 2 feet higher than observed values. There is less surface water available in this area than in eastern Martin and St. Lucie Counties, which implies that the users in this region may have to rely more heavily on withdrawals from the upper Floridan Aquifer System. Conversely, artificially high withdrawal rates may have been assigned to wells in the area northeast of Lake Okeechobee at the St. Lucie/Martin County boundary where differences between computed and observed heads are over 2 feet. Since the well density is higher in this area, property owners probably may not discharge all of the wells simultaneously, and some may not ever be in use. The overall uncertainty involved in quantifying agricultural withdrawals does not appear to justify arbitrary localized adjustments during the simulation process with such limited data availability. The total modeled area in which computed heads differ from observed heads by over 2 feet is about 115 square miles, or less than five percent of the active model nodes.

Discussion of Model Results

In general, the validated simulation appears to reflect observed conditions in the Upper Floridan Aquifer in September of 1983. Although the model is run as a transient simulation, the Upper Floridan Aquifer model reaches steady-state in a 12-month pumping period due to the low storage coefficient of the aquifer system combined with the high leakance coefficient of the intra-aquifer confining unit.

Of the total amount of water withdrawn from the Upper Floridan Aquifer at steady state, 0.3% is derived from storage and 99.7% is derived from a combination of upward leakance from the lower Floridan Aquifer System and lateral inflow from the boundaries of the modeled area. The two sources can not be differentiated because it is impossible to quantify the amount of water derived from leakance that leaves the modeled area as the lateral outflow required to maintain the configuration of the potentiometric surface. However, it appears that leakance is supplying the great majority of the contribution.

In the pumping simulation, model results show that the heads in the Lower Floridan range from 1.8 to 9.9 feet above the heads in the upper Floridan. The average difference in head (per node) between the two aquifer systems is about 4.5 feet. The average leakance flux (qL) from the lower Floridan to the upper Floridan is 1.64×10^{-9} ft/sec, or .62 in/yr. This rate is approximately three times greater than that observed in the pre-development simulation.

EVALUATION OF ALLOCATION CRITERIA

The purpose of the evaluation is to use the model to determine whether the 1.5 acre-inch criterion can be applied regionally to maintain positive potentiometric head relative to land surface or if not, what an acceptable alternative would be. Some inaccuracies are introduced because regional withdrawal stresses of the nature and magnitude of those introduced to the model are not fully compatible with the governing assumptions for both horizontal and vertical boundary conditions. However, It was felt that for purposes of evaluating the 1.5 acre-inch criterion to all of Martin and St. Lucie Counties, the incompatibilities were acceptable.

The model used to perform the evaluation differs from that previously described in two ways:

1. Further sensitivity analyses of the model demonstrated that upward leakance through the intra-aquifer beds is reasonably approximated if

uniform values for confining bed hydraulic conductivity (RATE) of 0.5E-7 ft/sec and confining bed thickness (M) of 100 ft. are used.

2. Likewise, diffuse upward leakance through the Hawthorn confining beds is successfully simulated using a uniform value of .132E-8 ft/sec, as reported by Tibbals (1981).

The validity of using a steady-state leaky aquifer finite difference model to evaluate a criterion derived from the Theis analytical model was tested by replicating the Theis model of the Orange Avenue Citrus Growers Association project. Withdrawals were added to the nodes in which the project is located, and these withdrawals were increased in progressive model runs until drawdowns of slightly less than 15 feet occurred. This occurred at a withdrawal rate of 17.3 MGD, which agrees reasonably well with the 14 MGD rate obtained from the Theis simulation. It was therefore concluded that the finite difference model was a valid means for evaluating the 1.5 acre-inch criterion regionally.

The positive potentiometric head for each active node was quantified. The average elevation for each node was determined, and this number was subtracted from the starting head value for that node. If the starting head was less than the average elevation, or if the node was comprised mainly of a water body, the available head was set to zero.

The first test simulated a withdrawal of 1.5 inches from all nodes with positive head relative to land surface. Figure 13 shows the results of the simulation. Although drawdown is not excessive, it is well below land surface is all nodes. This demonstrates that a maximum month criterion of 1.5 acre-inches cannot be applied regionally without ultimately causing free flow from Floridan wells to cease.

In the next test, the model was run iteratively to determine maximum withdrawal which could be made from each node while still maintaining some positive head. A starting withdrawal rate was calculated for each active node. It was determined experimentally that the best initial withdrawal rates (cfs) were obtained when the nodal transmissivity (ft^2/sec) was multiplied by available head (ft) and a constant of 13.8.

After each model run, the nodal withdrawal rates for the next run were established by multiplying the previous rate directly by the ratio of calculated drawdown to available drawdown for the node. No convergence acceleration logic was incorporated into the calculation. If the difference between calculated drawdown and available drawdown was less than ± one foot, closure was assumed, and the withdrawal rate was not recalculated.

It was noted that within the first few iterations, some nodes achieved drawdowns well below land surface from which no recovery was possible by reducing withdrawal rates within the nodes. It was determined that withdrawals could not effectively be made from nodes with available drawdown of six feet or less, because of superposed drawdown from other active nodes. Therefore, these nodes were set inactive.

Using the approach described, calculated drawdown in around 85% of the active nodes could be brought into convergence with available drawdown within about 20 iterative model runs. Any further runs achieved no significant additional convergence. Therefore, the final adjustments to withdrawal rates were made manually; rates in the nodes surrounding those where convergence had not occurred were raised or lowered as appropriate. Difficulties in convergence for the most part are a result of sharp topographic changes between nodes.

Table 1 depicts the final results of the model, expressed as inches per acre. Remaining potentiometric head above land surface at these withdrawal rates is shown by Figure 14. It is noted that by attempting to maximize withdrawals throughout the aquifer, rates as high as the proposed 1.5 acre-inch are obtained in few nodes.

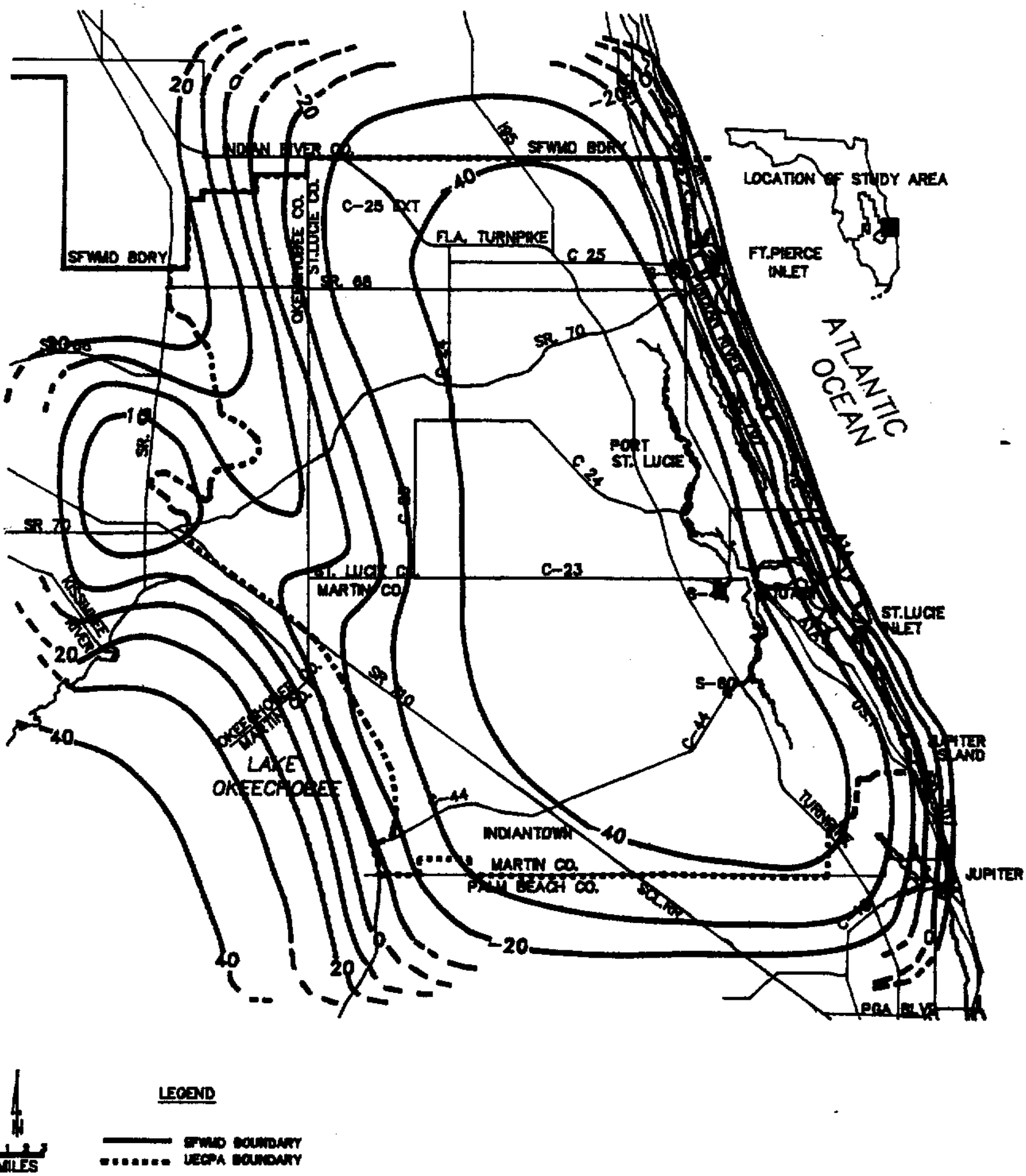

Figure 13. Water Level in Feet Below Land Surface Resulting from a Withdrawal Rate of 1.5 Inches (5.2 MGD) from Each of 378 Nodes

TABLE 1: WATER AVAILABILITY PER MODEL NODE WITHOUT DRAWING POTENTIOMETRIC HEAD BELOW LAND SURFACE

Row	Column	Nodal Withdrawal Rate (cfs)	(ac-in)
5	9	-0.9	0.3
5	10	-1.2	0.3
5	11	-1.0	0.3
5	12	-0.8	0.2
5	13	-0.9	0.3
5	14	-0.7	0.2
5	17	-0.8	0.2
5	19	-6.0	1.7
6	8	-0.7	0.2
6	9	-0.5	0.1
6	12	-1.5	0.4
6	13	-0.8	0.2
6	14	-0.2	0.1
6	17	-0.8	0.2
6	18	-0.3	0.1
6	19	-1.1	0.3
7	9	-0.5	0.1
7	10	-0.8	0.2
7	11	-0.9	0.3
7	12	-1.0	0.3
7	13	-0.7	0.2
7	14	-0.3	0.1
7	17	-0.4	0.1
7	18	-0.4	0.1
7	19	-1.6	0.5
8	9	-0.4	0.1
8	10	-0.4	0.1
8	11	-0.2	0.1
8	12	-1.8	0.5
8	13	-0.8	0.2
8	15	-0.7	0.2
8	16	-0.5	0.1
8	17	-0.4	0.1
8	19	-0.6	0.2
9	11	-0.4	0.1
9	12	-1.0	0.3
9	13	-0.2	0.1
9	14	-0.4	0.1
9	16	-0.2	0.1
9	18	-2.5	0.7
9	20	-3.0	0.9
10	11	-0.2	0.1
10	12	-1.0	0.3

Row	Column	Nodal Withdrawal Rate (cfs)	(ac-in)
10	13	-0.9	0.3
10	14	-0.4	0.1
10	17	-0.6	0.2
10	18	-1.6	0.5
10	19	-1.1	0.3
10	20	-2.1	0.6
11	3	-2.9	0.8
11	4	-3.5	1.0
11	10	-0.2	0.1
11	12	-1.2	0.3
11	13	-1.3	0.4
11	14	-0.6	0.2
11	16	-0.8	0.2
11	17	-0.6	0.2
11	18	-1.1	0.3
11	19	-1.4	0.4
11	20	-0.9	0.3
11	21	-2.8	0.8
12	4	-1.0	0.3
12	5	-0.2	0.1
12	10	-1.2	0.3
12	11	-0.6	0.2
12	12	-2.3	0.7
12	13	-2.1	0.6
12	14	-1.5	0.4
12	15	-0.5	0.1
12	16	-0.4	0.1
12	17	-0.2	0.1
12	18	-0.5	0.1
12	19	-2.0	0.6
12	20	-1.6	0.5
12	21	-2.5	0.7
13	3	-1.4	0.4
13	4	-0.5	0.2
13	5	-0.5	0.1
13	6	-0.2	0.1
13	10	-0.6	0.2
13	12	-0.7	0.2
13	13	-0.9	0.2
13	14	-0.8	0.2
13	15	-0.9	0.3
13	16	-1.1	0.3
13	17	-0.4	0.1
13	18	-0.6	0.2
13	19	-1.1	0.3

Row	Column	Nodal Withdrawal Rate (cfs)	Nodal Withdrawal Rate (ac-in)
13	20	-1.3	0.4
13	21	-1.1	0.3
13	22	-3.6	1.0
14	3	-0.9	0.3
14	4	-0.4	0.1
14	5	-0.6	0.2
14	6	-0.5	0.1
14	11	-0.9	0.3
14	12	-2.8	0.8
14	13	-0.9	0.2
14	14	-0.8	0.2
14	15	-0.2	0.1
14	16	-1.0	0.3
14	17	-0.5	0.2
14	18	-0.7	0.2
14	19	-1.1	0.3
14	20	-2.7	0.8
14	21	-0.5	0.1
14	22	-1.9	0.6
15	11	-0.6	0.2
15	12	-0.4	0.1
15	13	-1.4	0.4
15	14	-1.3	0.4
15	15	-1.2	0.3
15	16	-1.0	0.3
15	17	-0.6	0.2
15	18	-0.6	0.2
15	19	-1.2	0.4
15	20	-2.4	0.7
15	21	-1.9	0.5
15	22	-1.4	0.4
16	3	-2.7	0.8
16	4	-1.5	0.4
16	5	-3.0	0.9
16	6	-1.5	0.4
16	12	-1.4	0.4
16	13	-1.1	0.3
16	14	-0.6	0.2
16	15	-0.3	0.1
16	16	-0.4	0.1
16	17	-0.4	0.1
16	19	-1.2	0.3
16	20	-3.2	0.9
16	21	-2.3	0.7
16	22	-1.4	0.4
16	23	-4.4	1.3
17	3	-4.1	1.2
17	4	-4.0	1.1
17	7	-3.0	0.9

Row	Column	Nodal Withdrawal Rate (cfs)	Nodal Withdrawal Rate (ac-in)
17	12	-0.7	0.2
17	13	-1.1	0.3
17	14	-0.7	0.2
17	15	-0.4	0.1
17	16	-0.5	0.1
17	17	-0.2	0.1
17	18	-1.4	0.4
17	19	-0.3	0.1
17	20	-1.6	0.5
17	21	-2.5	0.7
17	22	-2.3	0.7
17	23	-3.1	0.9
18	3	-4.8	1.4
18	8	-3.5	1.0
18	9	-0.2	0.1
18	13	-0.5	0.1
18	14	-0.5	0.1
18	15	-0.5	0.1
18	16	-0.4	0.1
18	17	-0.7	0.2
18	19	-1.9	0.5
18	20	-1.8	0.5
18	21	-1.9	0.6
18	22	-1.4	0.4
18	23	-0.7	0.2
18	24	-5.0	1.5
19	3	-7.7	2.2
19	9	-2.0	0.6
19	10	-0.2	0.1
19	15	-0.3	0.1
19	16	-0.6	0.2
19	17	-0.4	0.1
19	19	-0.9	0.3
19	20	-1.0	0.3
19	21	-1.8	0.5
19	22	-2.5	0.7
19	23	-1.1	0.3
19	24	-1.3	0.4
19	25	-5.8	1.7
20	10	-1.0	0.3
20	16	-0.3	0.1
20	17	-0.8	0.2
20	18	-0.6	0.2
20	20	-0.8	0.2
20	21	-1.0	0.3
20	22	-3.1	0.9
20	23	-0.8	0.2
20	24	-1.4	0.4
20	25	-2.3	0.7

Row	Column	Nodal Withdrawal Rate (cfs)	Nodal Withdrawal Rate (ac-in)
21	10	-0.5	0.1
21	11	-0.8	0.2
21	18	-0.2	0.1
21	19	-0.7	0.2
21	20	-0.8	0.2
21	21	-1.2	0.4
21	22	-3.3	0.9
21	23	-2.7	0.8
21	24	-1.5	0.4
21	25	-1.8	0.5
21	26	-4.3	1.2
22	10	-0.5	0.1
22	11	-0.9	0.3
22	18	-0.4	0.1
22	19	-0.5	0.1
22	20	-1.0	0.3
22	21	-0.8	0.2
22	22	-0.5	0.2
22	23	-2.8	0.8
22	24	-2.2	0.6
22	25	-1.2	0.3
22	26	-2.4	0.7
23	11	-0.5	0.1
23	18	-0.4	0.1
23	19	-0.5	0.1
23	20	-1.0	0.3
23	21	-1.6	0.5
23	22	-1.5	0.4
23	23	-1.5	0.4
23	24	-2.6	0.7
23	25	-2.5	0.7
23	26	-2.1	0.6
24	11	-1.0	0.3
24	12	-1.0	0.3
24	18	-0.4	0.1
24	19	-0.5	0.1
24	20	-0.8	0.2
24	21	-1.8	0.5
24	22	-1.9	0.5
24	23	-1.9	0.5
24	24	-2.0	0.6
24	25	-2.4	0.7
24	26	-3.5	1.0
25	11	-2.5	0.7
25	12	-0.4	0.1
25	13	-0.4	0.1
25	14	-0.4	0.1
25	15	-0.4	0.1
25	16	-0.4	0.1
25	17	-0.4	0.1
25	18	-0.4	0.1
25	19	-0.5	0.1
25	20	-0.9	0.3
25	21	-0.9	0.2
25	22	-1.0	0.3
25	23	-1.4	0.4
25	24	-1.5	0.4
25	25	-2.4	0.7
25	26	-3.0	0.9
26	11	-5.4	1.6
26	12	-1.8	0.5
26	13	-0.8	0.2
26	14	-1.1	0.3
26	15	-0.8	0.2
26	16	-1.4	0.4
26	17	-1.0	0.3
26	18	-0.6	0.2
26	19	-0.8	0.2
26	20	-0.6	0.2
26	21	-1.1	0.3
26	22	-1.3	0.4
26	23	-1.8	0.5
26	24	-1.6	0.5
26	25	-2.7	0.8
26	26	-3.4	1.0
27	11	-7.8	2.2
27	12	-4.3	1.2
27	13	-3.9	1.1
27	14	-1.7	0.5
27	15	-2.1	0.6
27	16	-2.5	0.7
27	17	-2.9	0.8
27	18	-2.1	0.6
27	19	-3.3	0.9
27	20	-2.8	0.8
27	21	-2.5	0.7
27	22	-2.4	0.7
27	23	-2.8	0.8
27	24	-2.3	0.7
27	25	-2.4	0.7
27	26	-5.4	1.5

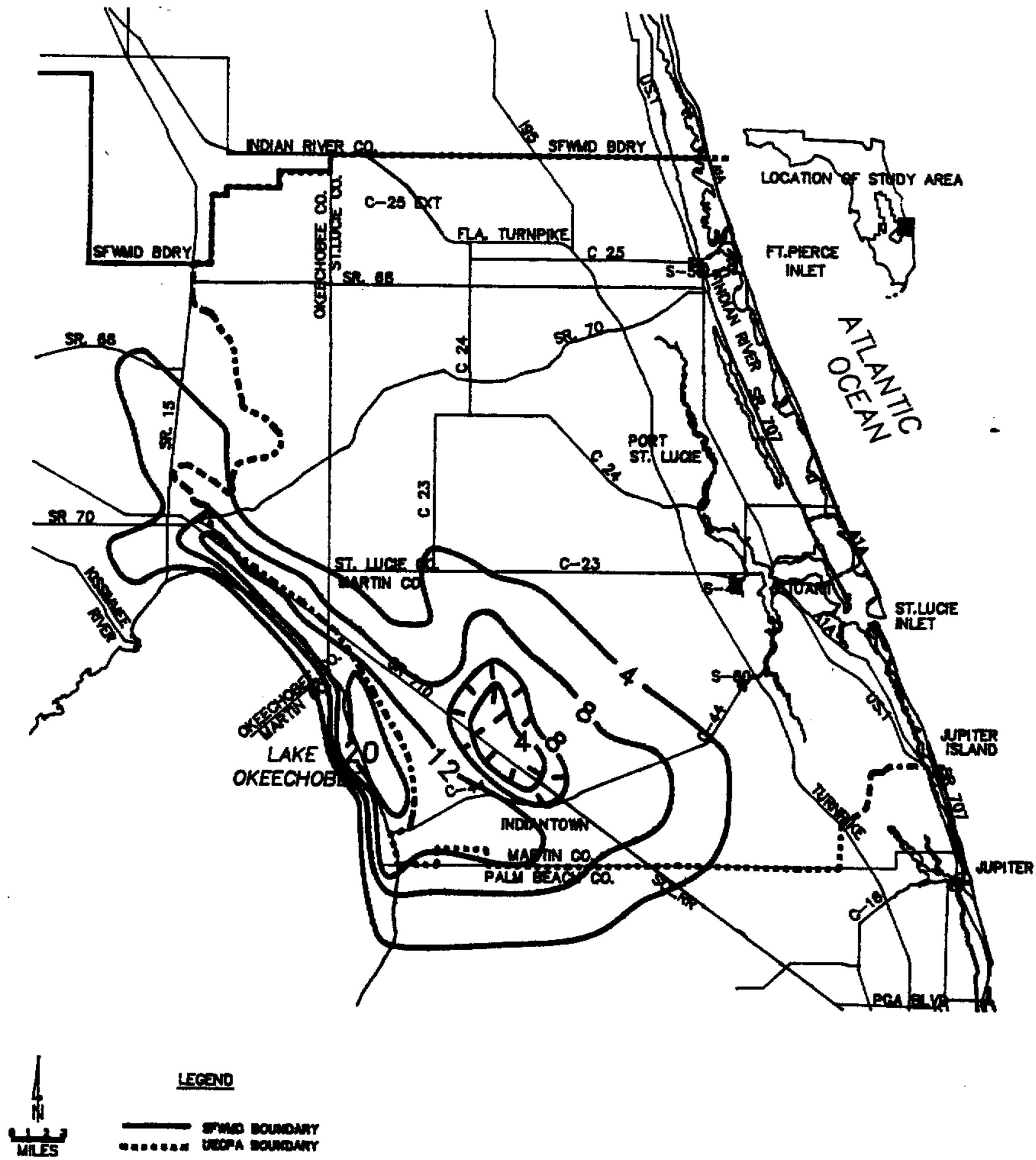

Figure 14. Potentiometric Head Above Land Surface at Withdrawal Rates Shown in Table 1

CONCLUSIONS AND RECOMMENDATIONS

It is concluded that:

1. Both the Theis analytical model and USGS two dimensional numerical model demonstrate the validity of limiting the maximum month withdrawal from the Floridan Aquifer System to 1.5 acre-inches at the Orange Avenue Citrus Growers Association project site.
2. The limitation is site-specific, being controlled by transmissivity, storativity, available head above land surface, the size of the project, the degree of on-site well interference, and lack of existing legal uses of the Floridan within the cone of depression.
3. The limitation can be validly applied in other similar situations, such as the St. Lucie West development of regional impact.
4. The 1.5 acre-inch maximum month limitation cannot be applied regionally; it generates drawdowns well below land surface.
5. Interim management of water use from the Floridan Aquifer System can be accomplished in two ways:
   a. The nodal discharges obtained from the version of the model in which water levels are drawn down to just above land surface can be considered to be available water at each of the nodes; new or revised allocations are some portion of that total.
   b. The existing conditions version of the model can be used to test new or increased water uses for cumulative impact.

Using the two dimensional numerical model in the quasi-three-dimensional configuration introduces inaccuracies which become unacceptable for long term water use management. Primarily, having a driving head for the leakance mechanism that does not change in response to head changes in the stressed aquifer overpredicts water availability and underpredicts water level declines. It is recommended that:

1. Interim water use management be accomplished by using current conditions configuration of the two-dimensional model for cumulative impact evaluations of new or increased allocations from the Floridan Aquifer System. Current stresses on the system are small enough that overprediction of water availability is of minor concern for the short term.
2. The data files for the two-dimensional model be adapted to the three-dimensional MODFLOW model. The most recent available potentiometric head and water use data is to be included in or added to these files, and the model recalibrated and revalidated.
3. A maintenance and update procedure for the three-dimensional model be developed and implemented by Resource Planning Department, incorporating periodic recalibration as new data becomes available.
4. The three-dimensional model be used in the next agricultural water use permit renewal cycle. The governing concept in applying the model can be to evaluate water uses as either cumulative impact on existing conditions or as apportionments of total projected water availability within model nodes based on maintaining potentiometric heads at slightly above land surface, as determined appropriate by Resource Control Department.

REFERENCES

Brown, M.P, 1980. Aquifer Recovery Test Data and Analysis for the Floridan Aquifer System in the Upper East Coast Planning Area: South Florida Water Management District, Technical Publication #80-1.

Brown, M.P. and Reece, D.E., 1979. Hydrogeologic Reconnaissance of the Floridan Aquifer System, Upper East Coast Planning Area: South Florida Water Management District, Technical Map Series #79-1.

Bush, Peter W., 1982. Predevelopment Flow in the Tertiary Limestone Aquifer, Southeastern United States; A Regional Analysis from Digital Modeling: U.S. Geological Survey Water Resources Investigations 82-905, 41 p.

Healy, Henry G., 1975. Potentiometric Surface and Areas of Artesian Flow of the Floridan Aquifer in Florida, May 1974: Florida Department of Natural Resources, Bureau of Geology, Map Series No. 73.

Johnston, R.H., Krause, R.E., Meyer, F.W., Ryder, P.D., Tibbals, C.H., and Hunn, J.D., 1980. Estimated Potentiometric Surface for the Tertiary Limestone Aquifer System, Southeastern United Staes, Prior to Development: U.S. Geological Survey, Open-File Report 80-406.

Miller, James A., 1982a. Configuration of the Base of the Upper Permeable Zone of the Tertiary Limestone Aquifer System, Southeastern United States: U.S. Geological Survey, Open-File Report 81-1177.

Miller, James A., 1982b. Geology and Configuration of the Top of the Tertiary Limestone Aquifer System, Southeastern United States: U.S. Geological Survey, Open-File Report 81-1178.

Miller, James A., 1982c. Thickness of the Tertiary Limestone Aquifer System, Southeastern United States: U. S. Geological Survey, Open-File Report 81-1124.

Miller, James A., 1982d. Geology and Configuration of the Base of the Tertiary Limestone Aquifer System, Southeastern United States: U. S. Geological Survey, Open-File Report 81-1176.

Mooney, Thomas R., 1980. The Stratigraphy of the Floridan Aquifer System East and Northwest of Lake Okeechobee, Florida: South Florida Water Management District, Technical Publication #80-9, 45 p.

Shaw, Jon E. and Trost, Sharon M., 1984. Hydrogeology of the Kissimmee Planning Area, South Florida Water Management District: South Florida Water Management District, Technical Publication #84-1, 235 p.

Shrivan, James A. and Karlinger, Michael R., 1983. Semi-Variogram Estimation and Universal Kriging Program, U. S. Geological Survey WRD-WRI-80-064.

Tibbals, C.H., 1981, Computer Simulation of the Steady-State Flow System of the Tertiary (Floridan) Limestone Aquifer System in East-Central Florida: U.S. Geological Survey Water Resources Investigations 81-681, 31 p.

Trescott, P.C., Pinder, G.F., and Larson, S.P., 1976. Finite Difference Model for Aquifer Simulation in Two Dimensions with Results of Numerical Experiments: U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 7, Chapter C 1, 116 p.

Wedderburn, Leslie A. and Knapp, Michael S., 1983. Field Investigation into the Feasibility of Storing Fresh Water in Portions of the Floridan Aquifer System, St. Lucie County, Florida: South Florida Water Management District, Technical Publication #83-7.

APPENDIX A

THEIS NON-EQUILIBRIUM MODEL

SIMULATION OF A WITHDRAWAL OF 14 MGD AT THE ORANGE AVENUE CITRUS GROWERS ASSOCIATION PROJECT SITE

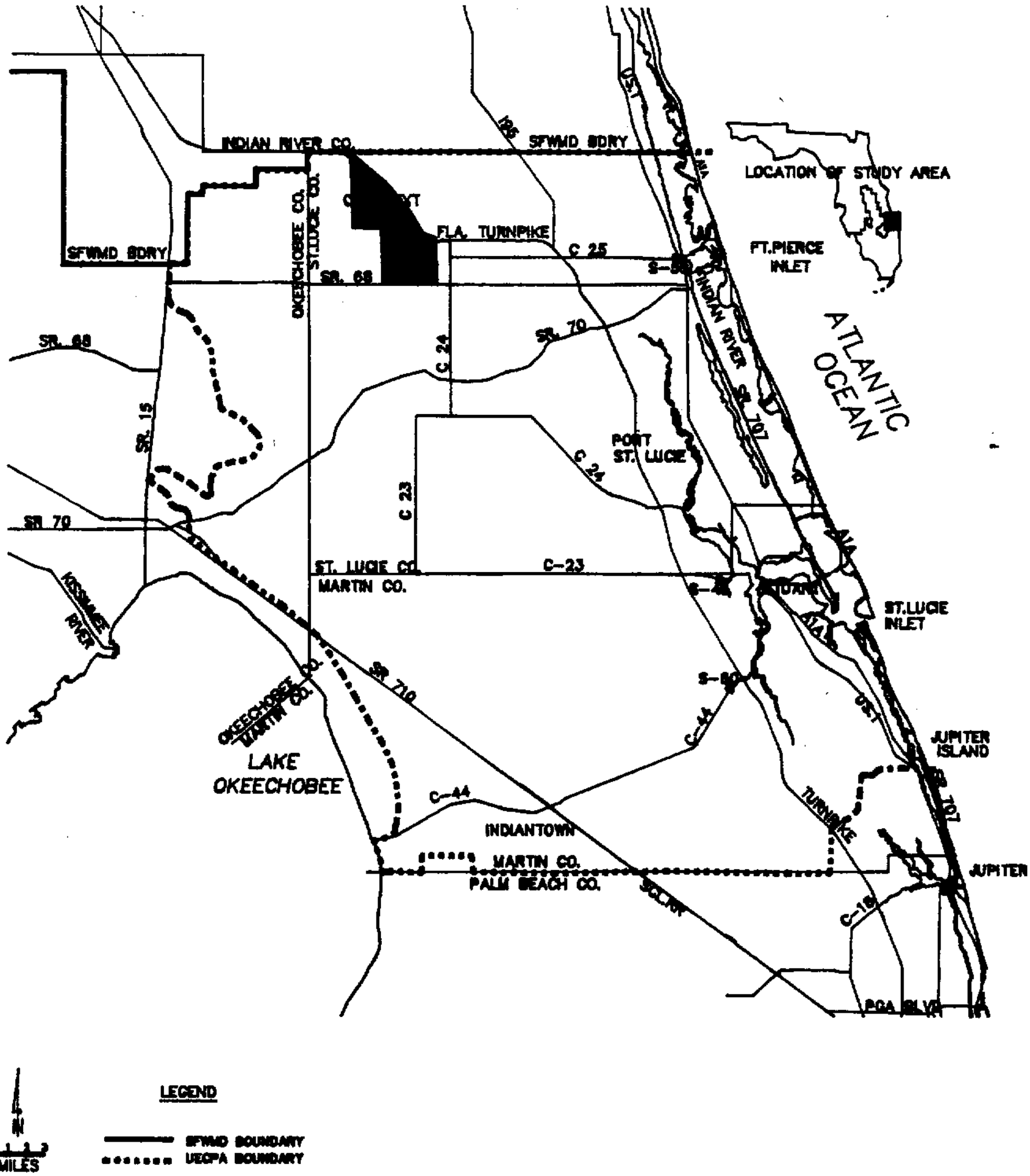

Figure A.1 Location of Orange Avenue Citrus Growers Association Project Site

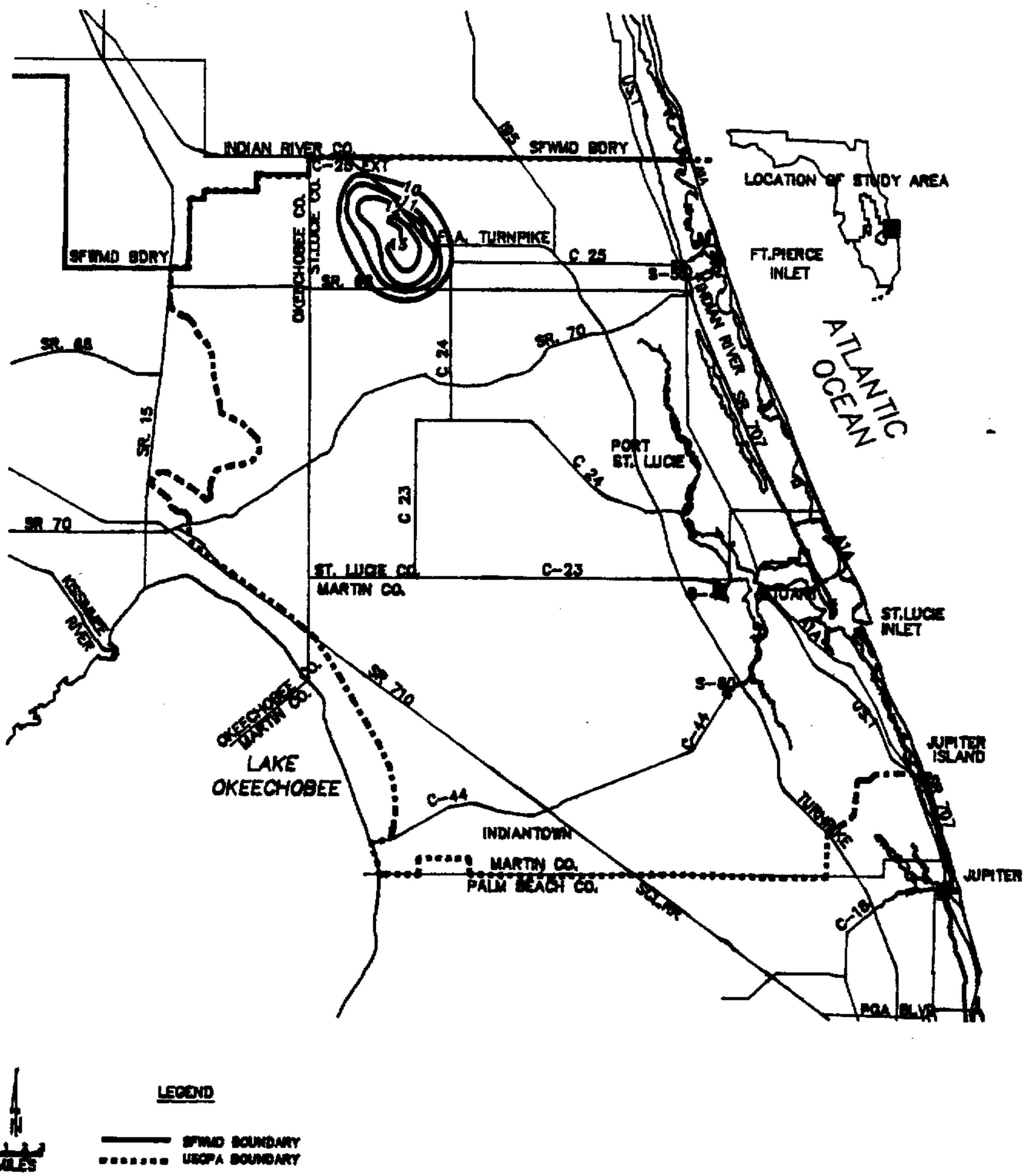

Figure A.2 Projected Drawdown Resulting from a Withdrawal of 14 MGD for 90 Days at the OACGA Project Site

SUMMARY OF INPUT DATA
NON-EQUILIBRIUM (THEIS) MODEL

TRANSMISSIVITY	=	500000.
STORAGE COEFFICIENT	=	.00050000
TIME (DAYS)	=	90.0000
NODE SPACING	=	2640.00

WELL DESCRIPTIONS

X-LOCATION	Y-LOCATION	Q (GPD)
12.00	12.00	233333.00
13.00	12.00	233333.00
14.00	12.00	233333.00
15.00	12.00	233333.00
16.00	12.00	233333.00
17.00	12.00	233333.00
12.00	13.00	233333.00
13.00	13.00	233333.00
14.00	13.00	233333.00
15.00	13.00	233333.00
16.00	13.00	233333.00
17.00	13.00	233333.00
12.00	14.00	233333.00
13.00	14.00	233333.00
14.00	14.00	233333.00
15.00	14.00	233333.00
16.00	14.00	233333.00
17.00	14.00	233333.00

WELL DESCRIPTIONS
(CONTINUED)

X-LOCATION	Y-LOCATION	Q (GPD)
12.00	15.00	233333.00
13.00	15.00	233333.00
14.00	15.00	233333.00
15.00	15.00	233333.00
16.00	15.00	233333.00
17.00	15.00	233333.00
12.00	16.00	233333.00
13.00	16.00	233333.00
14.00	16.00	233333.00
15.00	16.00	233333.00
16.00	16.00	233333.00
17.00	16.00	233333.00
14.00	17.00	233333.00
15.00	17.00	233333.00
14.00	18.00	233333.00
15.00	18.00	233333.00
8.00	19.00	233333.00
9.00	19.00	233333.00
10.00	19.00	233333.00
11.00	19.00	233333.00
12.00	19.00	233333.00
13.00	19.00	233333.00
14.00	19.00	233333.00
15.00	19.00	233333.00
8.00	20.00	233333.00

WELL DESCRIPTIONS
(CONTINUED)

X-LOCATION	Y-LOCATION	Q (GPD)
9.00	20.00	233333.00
10.00	20.00	233333.00
11.00	20.00	233333.00
12.00	20.00	233333.00
13.00	20.00	233333.00
14.00	20.00	233333.00
8.00	21.00	233333.00
9.00	21.00	233333.00
10.00	21.00	233333.00
11.00	21.00	233333.00
8.00	22.00	233333.00
9.00	22.00	233333.00
10.00	22.00	233333.00
11.00	22.00	233333.00
8.00	23.00	233333.00
9.00	23.00	233333.00
8.00	24.00	233333.00

--DISPLAY DRAWDOWNS ARE ACTUAL DRAWDOWN VALUES--

--ROUNDED UP ON 5 AND DOWN ON 4--